Electrostatic Phenomena

> "It frequently happens that in the ordinary affairs and occupations of life, opportunities present themselves of contemplating some of the most curious operations of nature."
>
> B. Thompson, Count Rumford (1753-1814)

OBJECTIVES

To gain a qualitative understanding of some electrical effects.

THEORY

The effects of "static electricity" were probably known to the ancients, but scientific understanding came slowly. Simple observation showed that electrified objects could exert forces on other objects, electrified or not. More detailed investigations demonstrated that when only one object was electrified the force was initially attractive. When both were charged, the force was repulsive if the objects had been charged the same way, but sometimes attractive if different methods had been used. A new property of materials was also discovered in the course of these electrical experiments. It was shown that some materials, now called insulators, could hold electricity, while other materials, called conductors, allowed it to move freely. With this insight it was easy to understand how electricity could be transferred between objects, or confined in one place for experiments.

By the end of the eighteenth century scientists generally agreed that the observed phenomena could be explained by assuming electricity was an odd sort of material substance. It could be contained or moved like a fluid, but no weight changes could be detected when an object was electrified. This "fluid" can be either positive or negative, as Ben Franklin observed, in order to account for the force observations. Although we might now consider this a rather quaint model, these simple ideas unified a large number of observations, as you will see.

EXPERIMENTAL PROCEDURE

This exercise calls for a number of qualitative observations, as well as some quantitative measurements. Concentrate on watching carefully and recording your observations clearly, so that you can write a coherent explanation of what you see.

Three kinds of plastic rods will provide electricity for our work today. When gently rubbed with dry paper they will become electrified. Except on the soggiest days, you should be able to get enough charge on any of the rods to hear a soft crackling sound. The sound indicates that the electricity is leaking off through the air, so further rubbing will not increase the electrification.

Most plastics are insulators, which is why you can retain a charge on the rods. By contrast, all metals and many liquids are conductors. The situation can become a bit confused, however, when an insulating material has a thin conducting film of water on the surface. This is quite likely to happen if the humidity is high and the insulator has been handled. The problem can be minimized by carefully cleaning the surfaces that you want to be insulating with alcohol. A gentle wipe with an alcohol dampened paper will also transfer charge from the rod to the paper and then to you, so it is a good way to remove charges from the rods when necessary.

The first experiments will use a device called an electroscope, which can detect the presence of electricity. It consists of a thin metal leaf hanging near a flat metal vane. The vane and leaf are connected to a metal disk and supported on an insulator. **The vane, the leaf and the metal disk are all electrically connected to each other.** The whole assembly is enclosed in a metal container to protect it from drafts. Your metal container should be connected to the "ground" (the circular) prong of an electrical outlet to avoid accumulating charge on the container.

Uncharged electroscope

You should start by grounding (removing any excess charge from) the electroscope by touching the metal disk with your hand. Next, electrify one of your rods by rubbing it with a dry paper napkin provided and then bring the electrified rod near, but not touching, the metal disk on top of the electroscope. What happens? Explain what you see in terms of the idea that electrification is the manifestation of the separation of negative and positive charges. **Hint: It is best not to charge the rod too much, nor to get it too close to the metal disk.** Otherwise, the electroscope leaf may move so far from the metal vane that it touches the can, confusing the results. What happens when you repeat this procedure with the other two rods?

Electroscope charged by contact

Now transfer some charge to the electroscope by rubbing one of the rods that you have lightly-charged against the metal disk of electroscope. Since the rod is an insulator you will need to touch all the parts of the rod from which you want to remove charge. A drop of alcohol on the plate may help the transfer by connecting the two solid surfaces. **You will know that you have successfully transferred charges to the electroscope if the silver-colored leaf in the electroscope remains in an elevated position after the rod is removed.** How does the electroscope respond to being charged? What happens if you now bring a charged rod near the metal disk? Try this with each rod in turn, and explain what you see. Organize your observation with a table like the one shown below. At this point you won't have enough information to know which rod is charged negatively or positively after being rubbed with paper, but you should be able to tell how each rod is charged relative to each other.

Example table:

Electroscope charged by	**Charged rod that was brought close to electroscope after charged**	**Result**
Clear flat rod	Clear flat rod	
	Gray rod	
	White rod	
Gray rod	Clear flat rod	
	Gray rod	
	White rod	
White rod	Clear flat rod	
	Gray rod	
	White rod	

Electroscope charged by induction

Discharge the electroscope by touching the plate with your hand. The leaf should return to the resting position. Now charge one of the rods, bring the charged rod close to the disk (but not touching), and then briefly touch the disk with your hand **While** the rod is close to the disk. After removing your hand from the disk, move the rod away from the disk. **<u>The charged rod should be the last thing that is moved away from the metal disk.</u>** This is called "charging by induction". What happens? How does the electroscope react to the different charged rods now? Is the charge on the electroscope the same or different than that on the rod you used to charge it? Organize your observation with a table like the one shown above. Explain what you see.

Coulombeter operation

We also have available a coulombeter, explained in Fig. 1, which can quantitatively measure electrification. To use the device, set the voltmeter to measure DC voltage by turning the knob to the position labeled V with a solid and dashed line. The meter reading is then proportional to the charge **on the portion of any object that is within the inner can**. If the meter does not read zero when the inner can is empty, push the "zero" button to remove the residual charge. You can choose the sensitivity by setting the toggle switch to 0.1

or 1.0 μF positions. **The output of this coulombeter is in unit of mV, which is proportional to the charge measured in unit of Coulomb. However, for this lab, you can report your results in unit of mV without converting to Coulomb.** When using the coulombeter, you **should not** let the object you are measuring touch any part of the inner or outer can.

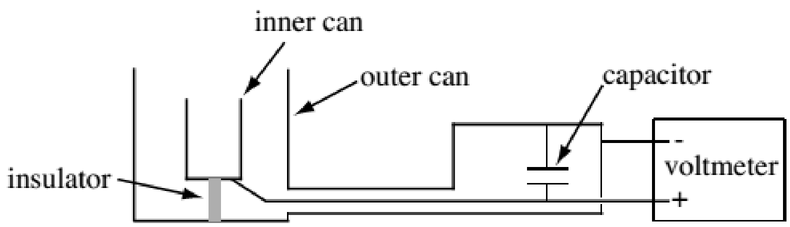

Fig. 1 Sketch of the coulombeter. It consists of a can connected to a capacitor. When a charged object is surrounded by the inner can, a proportional charge is induced on the capacitor. A voltmeter measures the potential on the capacitor, which is proportional to the induced charge. The meter reading is therefore proportional to the charge on the object. The outer can, which is connected to the earth, shields the instrument from stray charges.

To become familiar with coulombeter operation, use it to check the charge on each of the three rods. When using the coulombeter, it is important to note that the amount of charge induced on the capacitor is proportional to the total charges inside the inner can**. If you measure the charge on the same rod twice in a row, in order for the two measurements to be consistent with each other, the portion of the rod that is inserted inside the inner can must be about the same each time.** Are the relative signs of the different charged rods consistent with what you found from the electroscope experiments? Can you see the increase in charge as you rub the rod more?

Charged conductors

Charge one of the small metallic spheres by induction using whichever rod you can electrify most strongly (Each metallic sphere is attached to a thin plastic support rod.) Measure the charges on the rod that you used to charge the metallic sphere and the metallic sphere with the coulombeter. Are the relative charges on the rod and sphere consistent with your observation from before? (Be careful when handling the spheres. The support rods break easily.)

We have tacitly assumed that we transfer something, rather than creating it, when we electrify the rods or spheres. This idea can be tested by seeing if the amount of electrification is constant when we do a transfer. Electrify one or both spheres and measure their charge. Then touch them to each other and measure the charge on both spheres again. Is the sum of the charges between the two spheres about constant?

It might be objected that charge can only be transferred once it is on a metal, but that rubbing insulators is a different process. Check this possibility by removing the charges from **the clear flat rod and one of the round one rods**, by cleaning them with some alcohol. After cleaning the rods, use the coulombeter to make sure that the charges on both rods are close to zero. Now gently rub the rods together until you charge them both. Measure the charge on each rod. Is the result more consistent with rearrangement of a fixed amount of charges, or with creation of charges by rubbing? Try the same test with one of the rods and the paper you use to charge it. Do you get the same results? Why or why not?

Charge distribution on conductors

Our last project will be to examine the charge distribution on some objects. We can make a simple object by holding the two spheres together. Bring a charged rod close to the pair and then separate the spheres **while the rod is nearby**. Measure the charge on each sphere. Can you explain the sign and relative strength of the charges? Can you change the relative strength by changing the orientation of the pair with respect to the rod? You should include some sketches to help clarify your argument.

The other test subject is a metal soda can which is mounted on an insulating post. Electrify the can as strongly as you are able. (Charging by induction from the clear flat rod usually works best.) Be sure that one of the metal spheres is free of charge. By touching the charge-free sphere to the can at **various points**, you can sample the charge at the contact point. Use the coulombeter on the most sensitive scale, 0.1 μF, to find out how much charge you pick up from **at least 5 points on the surface of the soda can. Be sure to check the inside surfaces as well as outside surface. DO NOT re-electrify the soda can between measurements.** Summarize your result in a diagram, and explain your results?